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## Are “dwarf” ellipticals genuine ellipticals?

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**Abstract:** We review the systematic properties of “dwarf” elliptical (dE) galaxies, focussing on the relation between “normal” and “dwarf” ellipticals. In recent years, this relation has been described as “dichotomy” – based essentially on a discontinuity in central surface brightness. We show that, outside of 300 pc from the centre, the Sérsic profile parameters vary continuously from “normal” to “dwarf” ellipticals. The “dichotomy” is indeed restricted to the very central part, where differences also exist among “normal” ellipticals (E). Bright, nucleated dE’s closely resemble “normal” E’s also in their clustering and flattening properties. They may be genuine ellipticals, having no present-day late-type dwarf precursor from which they could have been manufactured. The non-nucleated dE’s (“dwarf spheroidals”) may be a different breed.

### 1. What to call a dE galaxy?

Elliptical galaxies are distinguished from spirals and late-type dwarfs by their smooth light distribution. Fainter than  $M_{B_T} \sim -18$  they divide up into two classes: compact ellipticals with high surface brightness, exemplified by M32, and diffuse ellipticals with low surface brightness, exemplified by the dwarf spheroidals in the Local Group (LG). Many different terms like dwarf ellipticals, dwarf spheroidals, spheroidals, or LSB galaxies are in use for the second class; there is no generally accepted definition. This led to some confusion. In particular, one debates whether faint ellipticals like M32 should be called dE. In our discussion we adopt the classification scheme worked out and illustrated in the Virgo cluster dwarf atlas of Sandage & Binggeli (1984), where the term “dwarf ellipticals” encompasses both local dwarf spheroidals and similar looking galaxies beyond the LG. Faint ellipticals with *high* surface brightness are referred to as ellipticals or compact ellipticals (cE) but never dwarf ellipticals. For a detailed discussion of the nomenclature issue see Binggeli (1994) and Kormendy & Bender (1994).

Within the dwarf elliptical family there is a subtype classified as dwarf S0 (dS0). These galaxies are among the brightest dwarf ellipticals, being a very rare species. In the Virgo cluster, for instance, only 25 dS0’s are known as compared to 800 dE’s. The dS0’s show morphological characteristics of a bulge-to-disk transition which is typical for classical S0’s. However, a bar feature or simply high apparent flattening (Sandage & Binggeli 1984, panel 8) are other

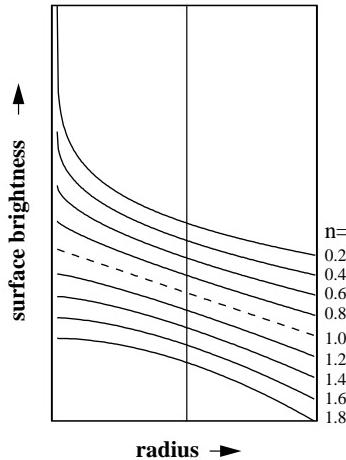
reasons why a dwarf galaxy is called a dS0 rather than a dE. Interestingly, dS0's seem to be statistically indistinguishable from bright dE's with respect to their mean radial surface-brightness profile (Binggeli & Cameron 1991 hereafter BC91) and other photometric parameters (Ryden et al. 1997). However, first kinematical data for a small number of dE&dS0's give preliminary evidence that galaxies tagged with the label "dS0" are the only rotationally supported early-type dwarfs (Bender 1997).

## 2. The E–dE dichotomy and how it disappears

One of the classical representations of the galaxian manifold is a plot of the absolute magnitude  $M$  versus the observed central surface brightness  $\mu_0$  (Kormendy 1985; Binggeli 1994). In that plane, the two elliptical families appear to fall into two distinct sequences. While E's and E-like bulges have higher central surface brightness with fainter luminosity, these parameters are anti-correlated for the dE's. Until recently there was the hope to get resolved core photometry for more distant low-luminosity ellipticals in the magnitude range  $-18 < M_{B_T} < -15$ , where members of both E's and dE's coexist, to answer the question whether there is a bridge between the two families or a gap. However, Kormendy and collaborators (Kormendy et al. 1994; Kormendy & Bender 1994) showed convincingly that even with the power of CFHT and HST the cores of these galaxies remain unresolved down to a radius of 0.1 arcsec. It will thus be impossible in the near future to discern where these key objects are located in the  $M-\mu_0$  diagram. A presently more promising approach to the problem of the E–dE dichotomy is to explore the deviations of light profiles from the classical  $R^{1/4}$ -law or exponential law, which we discuss in the following.

In first order the surface brightness profiles of dE's are well approximated by straight lines reflecting the exponential decay of the light intensity with radius (Faber & Lin 1983). But it was emphasized by Caldwell & Bothun (1987) and BC91 that there are *systematic* deviations from this exponential law in the central region. Most dE's brighter than  $M_{B_T} = -16$  have an inner luminosity excess above the exponential (BC91, Fig. 8), which is *not* due to the star-like nucleus some of these dwarfs have, but to a shallow extension over several hundred of parsecs. On the other hand, very faint dwarfs typically exhibit a central decrement relative to an exponential law. A closer inspection of a collection of Virgo dwarf profiles (BC91, Fig. 4) reveals that the *shape*, or *curvature* of the profile varies with total luminosity. The link between the two elliptical families are the brightest dE's, which come confusingly close to normal E's in their profile shape. The observed variation motivated Young & Currie (1994, actually preceded by Davies et al. 1988) to approximate dwarf profiles with the generalized exponential function initially introduced by Sérsic (1968):  $I(r) = I_0 \exp[-(r/r_0)^n]$ ,  $0 < n$ , where  $I(r)$  is the light intensity at radius  $r$ ,  $I_0 = I(0)$ , and  $r_0$  is the scale length. Note that most of our "giant colleagues" are using  $1/n$  instead of  $n$ . The corresponding integrated light profile (growth curve) is given by  $GC(r) = \frac{2\pi I_0 r_0^2}{n} \cdot \gamma[2/n, (r/r_0)^n]$  where  $\gamma(a, x) = \int_0^x \exp(-s)s^{a-1}ds$ .

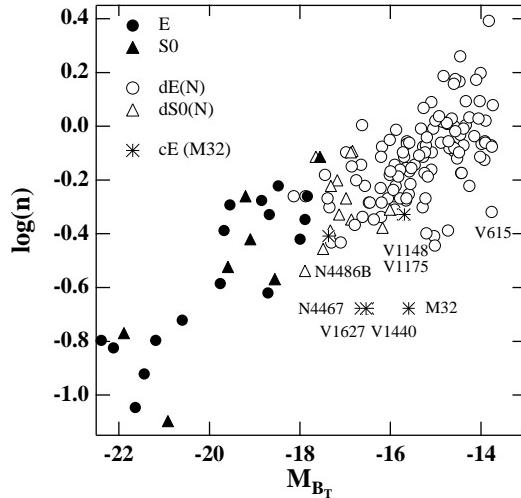
Obviously, the Sérsic profiles encompass both the  $R^{1/4}$ -law and the exponential law ( $n = 1$ ) by allowing the shape parameter  $n$  to vary. For  $n > 1$  the profiles become flat in the central part, just as observed for faint dE’s (see Fig. 1). What was qualitatively known from Virgo dwarf profiles was thus quantified by Young & Currie (1994), who found a strong correlation between  $n$  and total luminosity for a sample of Fornax cluster dwarfs. The authors even used the relation to measure the distance to the Fornax cluster and later applied it also to the Virgo cluster (Young & Currie 1995), where the observed scatter in the  $n-M$  relation is much larger. Young & Currie ascribe the large scatter to the depth of the Virgo cluster, assuming a universally small dispersion of the  $n-M$  relation. However, Binggeli & Jerjen (1996) show that this assumption is flawed and that the claimed filamentary structure of Virgo is unreal. The  $n-M$  relation is probably of no use for distance measurements. For details the reader is referred to Binggeli & Jerjen (1996).



**Figure 1.** Curvature variation of the Sérsic profiles as a function of the shape parameter  $n$ . The vertical line indicates the radius at which all functions have the same slope.

To investigate the shape variation in greater detail we have analysed the light profiles of an unbiased sample of dE&dS0’s from the photometric survey of Virgo dwarfs (BC91; Binggeli & Cameron 1993). The galaxy sample is complete down to  $M_{B_T} = -14$ . The data are based on high-resolution photographic plates from the Las Campanas 100-inch du Pont telescope. We fitted the  $GC(r)$  function as given above to the growth curve of each sample galaxy. Errors in the intensity counts were assumed to be Poissonian. Because our prime interest is in the *universal* shape signature of the profile, we spared out the innermost  $3''$  of the profiles (or  $\sim 300$  pc, assuming a distance modulus of 31.75 for Virgo, Sandage & Tammann 1995). In this way central features such as the nuclei some of these dwarfs have are excluded from the fit. The outer fit limit was taken at the surface brightness radius  $r_{27}$ . In Fig. 2 we plot  $\log(n)$  versus luminosity for our Virgo sample (open symbols). The dwarfs follow a clear trend from larger  $n$  for

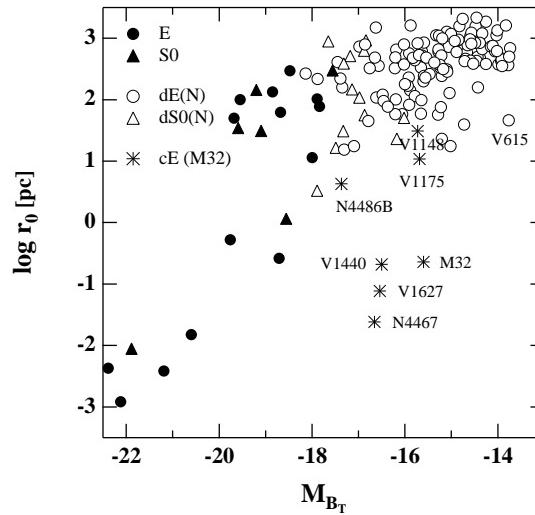
faint dwarfs to smaller values for brighter galaxies, as it was reported in earlier studies. However, the scatter of the relation is considerable with  $\sigma_{\log(n)} = 0.14$  and  $\sigma_{M_{B_T}} = 1.37$ . This indicates the large error which has to be expected from distances based on this method. V615 appears to be the only dE not following the general trend. The reason is its very extended nucleus ( $r_{nuc} > 3''$ , Fig. 4 in BC91) which affected the profile fit in this particular case. Thus the galaxy can not be seen as a real deserter. We compare our dwarf data with a parameter set published for E&S0's by Caon et al. (1993). Their good and fair quality fits have been added in our diagram as filled symbols. Obviously, they follow the same trend as the dwarfs, with about the same scatter. The relation for E's and that for dE's smoothly and continuously merge into each other, giving the impression of one global relation for dwarf and giant ellipticals over an 8 magnitude range. A ML fit gives:  $\log(n) = 1.40(\pm 0.10) + 0.10(\pm 0.01)M_{B_T}$ . Even the supergiant cD galaxies seem to fit into this sequence of profile shapes (Graham et al. 1996).



**Figure 2.** The  $\log(n)$ -luminosity relation for early-type galaxies.

In the diagram we have further added data for cE galaxies, which include about half of the known Virgo cE sample (N4486B, N4467, V1148, V1175, V1440, and V1627) plus M32, for which we have fitted a generalized profile to the photometric data of Peletier (1993). Within a narrow range of luminosity, this galaxy type shows a large variety of shapes, obviously not following the trend of the other ellipticals. An individual look with respect to projected distance and relative velocity to a bright parent galaxy gives some hint that the deviation from the “main sequence” might be correlated with the degree if isolation. V1627, V1440, and M32 are close companions of a giant galaxy (M89, N4548, and M31, respectively), where tidal stripping during or after formation may have occurred (Faber 1973, Burkert & Truran 1994). On the other hand, V1148 and V1175 appear to be rather isolated in the Virgo cluster. Less clear is the situation for N4467 and N4486B where relative velocities to possible parent galaxies are high

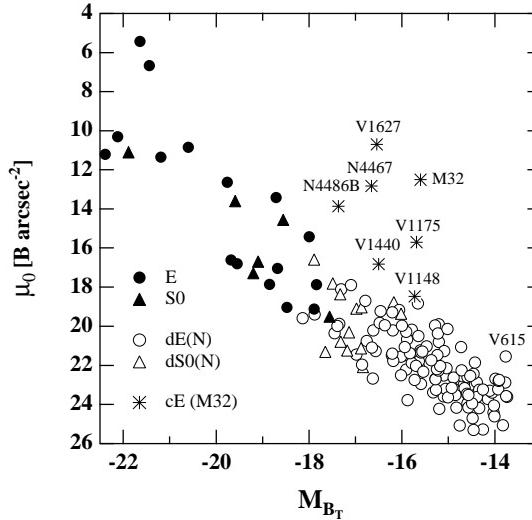
(N4467:  $\Delta v = 501 \text{ km s}^{-1}$  with M49; N4486B:  $\Delta v = 228 \text{ km s}^{-1}$  with M89). The same is seen in Figs. 3 and 4 where we show the correlations between the two other Sérsic parameters  $r_0$  and  $\mu_0$  and luminosity. In both diagrams the cE’s are the only type which deviates clearly from the relation exhibited by the dE&dS0’s and E’s. Overall, these results support the view that the cE’s are a special kind of elliptical galaxies; they have shapes like giants but luminosities like dwarfs. It is unlikely that they are low-luminosity representatives of giant ellipticals. Bender et al. (1992) suggested that cE galaxies may be bulges of failed disk galaxies that could not acquire a significant disk component due to the tidal field of a nearby massive galaxy. However, this possibility seems to contradict the observed  $\log(n)$ -luminosity relation for bulges of spiral galaxies (Andreakis et al. 1995).



**Figure 3.** The scale length–luminosity relation for early-type galaxies.

Fig. 4 is of special interest because it represents the model-based analogy of the  $M-\mu_0$  diagram mentioned in the beginning. Compared to the model-free ( $M, \mu_0$ ) values, the Sérsic fits for brighter ellipticals ( $M_{B_T} < -21$ ) yield central surface brightnesses which are systematically *higher*. This shift resolves the E-dE dichotomy by moving up all these galaxies onto the locus of the universal relation, i.e. to brighter central surface brightness with increasing luminosity followed by all ellipticals (except the cE’s) below this magnitude limit. It is well-known that at about this luminosity ( $M < -21$ ) many other properties within the E family are changing. It is roughly the transition point from resolved to unresolved cores (Kormendy et al. 1994); from boxy to disky shapes (Nieto et al. 1991); from E1.5 to E3 apparent flattening (Tremblay & Merritt 1996); and from anisotropic to rotationally supported systems (Davies et al. 1983). From our profile shape correlation (Fig. 1) we would “predict”, by extrapolating inwards, a high central surface brightness for the brightest ellipticals; which is not observed in the resolved cores. A brief discussion about the reason for

this apparent discrepancy leads us first to the question about the origin of the  $\log(n)$ -luminosity scaling law.



**Figure 3.** The central surface brightness–luminosity relation for early-type galaxies.

For the E&S0 galaxies it was shown (Einasto & Caon 1993) that  $n$  is not correlated with the underlying environmental density. This result is consistent with the fact that dwarfs and giants have both very similar clustering properties but obviously different profile shapes. It must be rather something intrinsic, such as the total mass, which determines the global light distribution. If similar formation mechanisms were at work for these galaxies, the only difference might be the depth of the gravitational potential. This idea has been suggested by Young & Currie (1994) and Andredakis et al. (1995) and is getting some theoretical support from models of violent relaxation processes (Hjorth & Madsen 1995). In the case of dwarf galaxies there is common agreement that the specific light distribution, i.e. the diffuseness, is a result of low mass. With decreasing mass (fainter luminosity) the potential becomes more shallow and stellar processes are shaping the appearance of the system accordingly. Supernova-driven winds and winds of massive stars remove the gas from the centre and subsequently star formation will shift to the outer regions of the galaxy leading to a plateau-like light profile. At higher luminosities the ellipticals have a more and more cuspy light distribution along with an extended halo (cf. Fig. 1) – both consequences of a small value of  $n$ . However, what is observed is a light deficiency relative to the overall profile shape concentrated on the innermost region ( $r < 300\text{pc}$ ) of bright ellipticals ( $M_{BT} < -21$ ). Here it is important to note that the core regions of elliptical galaxies are special and unique. There one finds black holes (Kormendy & Richstone 1995) as well as stellar and gaseous disks (Kormendy et al. 1994; see also these proceedings). Hence, the *observed*  $\mu_0$  of a giant elliptical is *not* a good tracer of its global galactic properties but is rather a foot print of the individual (dynamical and dissipational) history of its core region.

Outside the innermost 300 pc, normal and dwarf ellipticals show a great continuity in their structural properties. In contrast to the previous emphasis of a dichotomy between giants and dwarfs (Wirth & Gallagher 1984, Kormendy 1985, BC91), this suggests that *the diffuse, low-surface brightness dwarf galaxies are the true low-luminosity extension of the classical giant ellipticals*. In the following we will summarize other properties common to both galaxy families to provide further evidence that in many respects they are indistinguishable. A review on the properties of dwarf elliptical galaxies in general can be found in Ferguson & Binggeli (1994, hereafter FB94).

### 3. More systematic properties in comparison

#### 3.1 *Flattenings and kinematics*

Binggeli & Popescu (1995) studied 260 photometrically measured and 800 eye-estimated apparent ellipticities of all different types of dwarf galaxies in the Virgo cluster. They found good agreement between the flattening distributions of giant ellipticals (Franx et al. 1991) and *nucleated dE’s*. Among the dE&dS0 galaxies, the nucleated dE’s tend to be significantly rounder than their non-nucleated counterparts. This was noted before by Ferguson & Sandage (1989) and Ichikawa (1989) and confirmed the results by Ryden & Terndrup (1994). Non-nucleated dE’s, late spirals, Im’s, and BCD’s show all very similar distributions, with some hint that dE’s and Im’s are slightly rounder than the rest. The flattening distribution of the dS0’s is comparable with that of spiral galaxies, indicating the disk-like nature of these systems. Concerning the 3-dimensional shape, the situation for the early-type dwarfs seems to be quite similar to normal ellipticals. A modest triaxiality explains the ellipticity distribution of dE’s much better than a pure oblate model.

The question of rotation in dwarf ellipticals has been addressed only recently because of required spectroscopic work at a faint level of surface brightness. The sparse results for only six galaxies suggest that dwarf ellipticals are not supported by rotation (see FB94, Sect. 3). This excludes at least some of the dS0’s, e.g. UGC7436, a dS0,N in the Virgo cluster (Bender 1997). However, a much larger kinematic sample is needed to explore the kinematic nature of dwarf ellipticals and the possible differences between dE’s and dS0’s.

#### 3.2 *Luminosity function and spatial distribution*

The intermediate magnitude range between faint E’s and faint dE&dS0’s is populated by the nucleated dE’s and dS0’s. These brightest dwarf ellipticals are unique in the sense that they can only be found in clusters or as close companions to massive parent galaxies. In fact, all known dE&dS0’s brighter than about  $M_{B_T} - 16$  are cluster members. For instance, the brightest dE&dS0’s in Virgo, Fornax, or Centaurus are -18 (Sandage et al. 1985), -17.5 (Ferguson & Sandage 1988, hereafter FS88), and -18 (Jerjen & Tammann 1996), respectively. On the other hand, N205 is the brightest dwarf elliptical in the LG with only  $M_{B_T} = -15.6$ , and the nearby Cen A group has no dwarf brighter than  $M_{B_T} = -13$  (Jerjen et al. 1996). A trace of this special population of dwarf ellipticals

in clusters can be found in the shape of the type-specific dE&dS0 luminosity function (LF). The LF of the Virgo dwarf ellipticals (Sandage et al. 1985, Fig. 6) exhibits a clear plateau with a maximum at  $M_{B_T} \sim -15$  before it rises steeply to fainter magnitudes. A similar signature can be found in the LF of Fornax cluster dE&dS0's (FS88, Fig. 17). One could think of a superposition of a Gaussian and a Schechter function representing the nucleated and non-nucleated dwarf populations, respectively.

It is a general result from the morphology-density relation of dwarfs (FS88; Binggeli et al. 1990; Vader & Sandage 1991) that early-type dwarfs are the most strongly clustered of all galaxy types. However, there seem to exist isolated, faint, non-nucleated dE's such as the recently discovered Tucana dwarf, which indicates again the importance of a discrimination between the different subtypes to get the full information. Binggeli et al. (1987) have qualitatively shown that the nucleated dE's follow the strongly clustered projected distribution of giant ellipticals in the Virgo cluster. The non-nucleated dE's are slightly more spread out. This trend gained further support from a distribution study by Ferguson & Sandage (1989) where significant differences could be found between nucleated and non-nucleated dE's brighter than about  $M_{B_T} = -14$ . The latter follow the shallow cluster profile exhibited by the spirals and irregulars, hinting at a possible evolutionary link between non-nucleated dE's and late-type galaxies. From a recent deep redshift survey of the Centaurus cluster (Stein et al. 1996) we also got first results from the third dimension (velocity). The bright dE&dS0's are the only galaxy type which has (1) a Gaussian velocity distribution and (2) a mean redshift similar to the cluster mean, demonstrating that they trace the highest densities. All other galaxy types exhibit non-Gaussian, irregular velocity distributions.

### *3.3 Are dE's evolved irregulars?*

The evolutionary connection between dE&dS0's and irregular dwarfs Im&BCD's is not well understood. Although many intermediate-type dwarfs were studied where we may be witnessing the conversion of an irregular to a dE (e.g. ESO359-G29, Sandage & Fomalont 1993), and several physical processes are known which can serve as transformation mechanisms (FB94), no consistent picture of dwarf galaxy evolution has emerged yet. What has become clear over the last 10 years, though, is that it will be very hard, if not impossible to manufacture a bright, cuspy dE from a bright late-type dwarf like the LMC by *any* mechanism. Simple gas removal by ram pressure stripping would leave the remnant with much too low surface brightness, including a missing nucleus, as well as too low metallicity (Binggeli 1986, Bothun et al. 1986, Davies & Phillipps 1988, FB94). Clearly, the gas would have to be turned into stars instead of being lost, but it is not clear *how*. Also, there is a kinematic dichotomy between the non-rotating and roundish dE's and the rotating, disk-like irregulars. It seems that the present-day bright irregulars are not the precursors of the bright dE's. In contrast, there is no such problem for the faint dwarfs. Faint irregulars are thick and slowly rotating. They are easily turned into dwarf spheroidals, some of which, like Carina, show

indeed the sign of fairly recent star formation (see FB94). Hence also with respect to secular evolution, at least the *bright* dwarf ellipticals ( $M > -16$ ) are as close or as far from late-type galaxies as normal ellipticals.

#### 4. Conclusions

We have shown the existence of a *global* and *continuous* relation between Sérsic’s profile shape parameter  $n$  and absolute magnitude for E and dE galaxies. The continuity in luminosity profile characteristics holds outside the innermost 300 pc of the galaxies. The E–dE dichotomy, i.e. high-surface brightness of normal E’s versus low-surface brightness of dwarf E’s at intermediate luminosities, is restricted to the core region, where “special effects” (stellar disks, black holes, prolonged dissipation etc.) begin to dominate over the global structure. We have listed further family bonds between normal and dwarf ellipticals: both have very similar flattenings and clustering properties, and at least the bright dwarfs cannot be explained as evolved irregulars. One weak point here may be the kinematics: faint normal ellipticals are rotation-supported, bright dwarf ellipticals are apparently anisotropic; but the data for dwarfs is still too sparse for a final statement. Overall it appears that “normal” and “dwarf” ellipticals form *one* sequence, *one* family of stellar systems which must have a common origin. In this sense dwarf ellipticals are the genuine low-luminosity extension of giant ellipticals, and the question put in the title of this contribution has to be answered with an emphatic YES!

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